STATUS OF CLIC STUDIES

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LCWS 2000 FERMILAB
24th October 2000

CLIC

CLIC study of a 0.5 to 5 TeV e+e- Linear Collider

MOTIVATION

- **Want to be in a position to propose an e± Linear Collider for the post-LHC era covering a c.m. range of energies from 0.5 - 5 TeV**

  (Maximum energy well above that proposed by any of the other LC studies)

- **Want to build this machine for lowest possible cost using most cost-effective technological solutions**

CERN CLIC study members

CERN scientific staff presently participating in machine studies

R.Assmann
F.Becker
R.Bossart
H.Burkhardt
H.Braun,
G.Carron
W.Coosemans
R.Corsini
E.D'Amico
J.P.Delahaye
S.Doebert
A. Ferrari
G.Geschonke
J.C.Godot
L.Groening
G.Guignard
S.Hutchins
B.Jenneret
E.Jensen

T.Kamitani
A. Millich
P.Pearce
R.Pittin
J.P.Potier
L.Rinolfi
T.Risselada
P.Royer
F.Ruggiero
D.Schulte
G.Suberlucq
I.Syratchev
L.Thorndahl
H.Trautner
A.Verdier
I.Wilson
W.Wuensch
F.Zimmermann
F.Zhou

In total 38 - many part time ⇒ overall effort ~ 27 FTEs

Collaborating with many other laboratories

- **BERLIN Technical University (Germany) : Planar structure design studies**
- **DARESBURY (England): Damping ring design and final focus studies.**
- **DESY (Germany): Coherent synchrotron radiation studies, beam delivery design**
- **INFN / LNF (Italy): Combiner rings and transfer lines for CTF3**
- **Jefferson National Laboratory (USA): Coherent synchrotron radiation studies**
- **JINR and IAP (Russia): Structure tests using 30 GHz RF power source**
- **KEK (Japan): ATF -photo-injectors - modulators**
- **LAL (France): Electron guns for CTF3**
- **LLBL/LBL (USA): Two-beam scheme with Relativistic Klystron**
- **RAL (England): Lasers for CTF3 and CLIC photo-injectors**
- **Royal Institute of Stockholm (Sweden): Beam loading compensation cavities for CTF2.**
- **SLAC (USA): High gradient testing, GaAS photocathodes, structure design, multi-TeV LC designs, CTF3 drive beam injector design**

Operating energy range

- **Collider has been optimized for 3 TeV with L = 10^{35} cm^{-2} s^{-1}**
- **Designed such that construction can be staged without making major mods.**
- **First stage would possibly be HIGGS Factory at 0.5 TeV with L= 10^{34} cm^{-2} s^{-1}**
- **Second stage would provide the very desirable e± data ≈ 1.5 TeV to complement the p-p data from LHC, and at 3 TeV we should be breaking new ground.**
- **Final stage would be 5.0 TeV with L > 10^{35} cm^{-2} s^{-1}**

CLIC study of a 0.5 to 5 TeV e+e- Linear Collider

The CLIC scheme has two very distinctive features

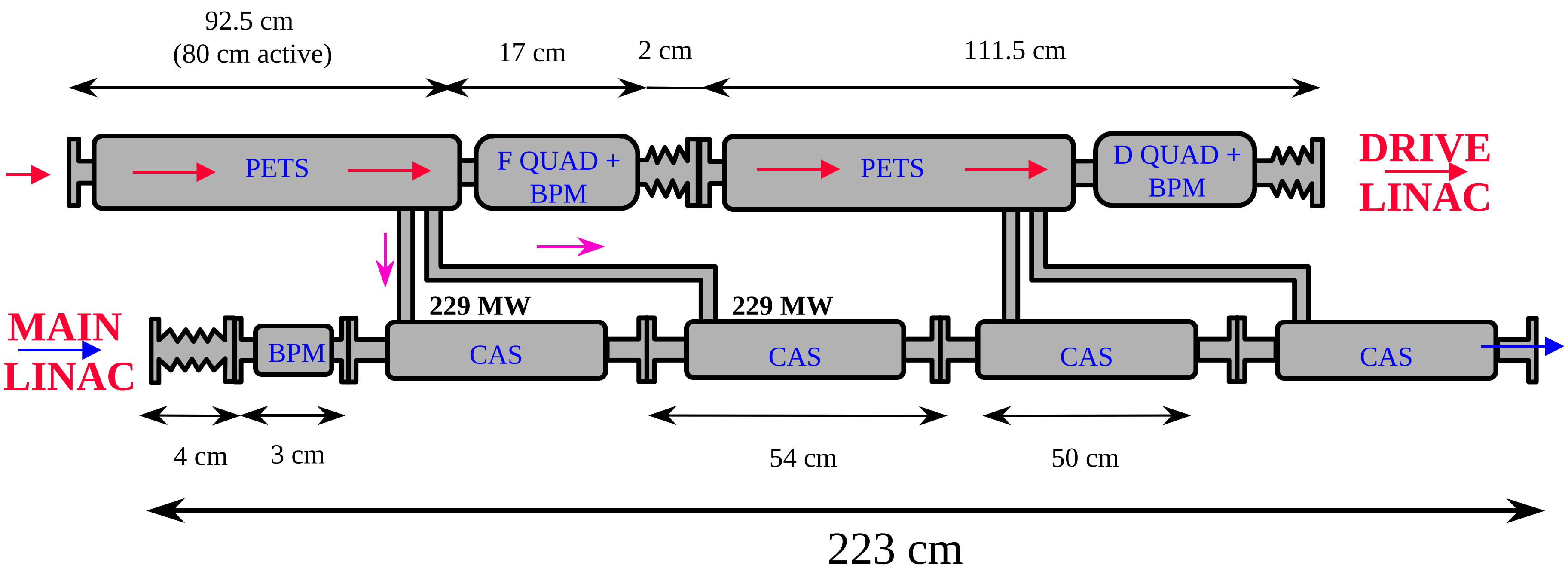
- **It accelerates the beam using high frequency (30 GHz) normal-conducting structures operating at high fields (150 MV/m) - this reduces the LENGTH and in consequence, the COST of the linac.**

  (For 3 TeV - 150 MV/m - length 37.5 km)

- **It extracts its RF power from a high-intensity low-energy drive beam running parallel to the main linac. This RF power generation scheme we believe to be the most cost effective way to produce multi-TeV beams.**

CLIC Two-Beam Acceleration (TBA) scheme

- **RF power to feed the 30 GHz accelerating structures extracted by special decelerating structures from high-intensity/low-energy drive beam running parallel to main beam.**
- **Two-beams separated by ~ 60 cm - so RF power generated locally where it is needed.**
- **Drive beam dumped after extracting about 85 % of its energy.**



Tunnel Layout

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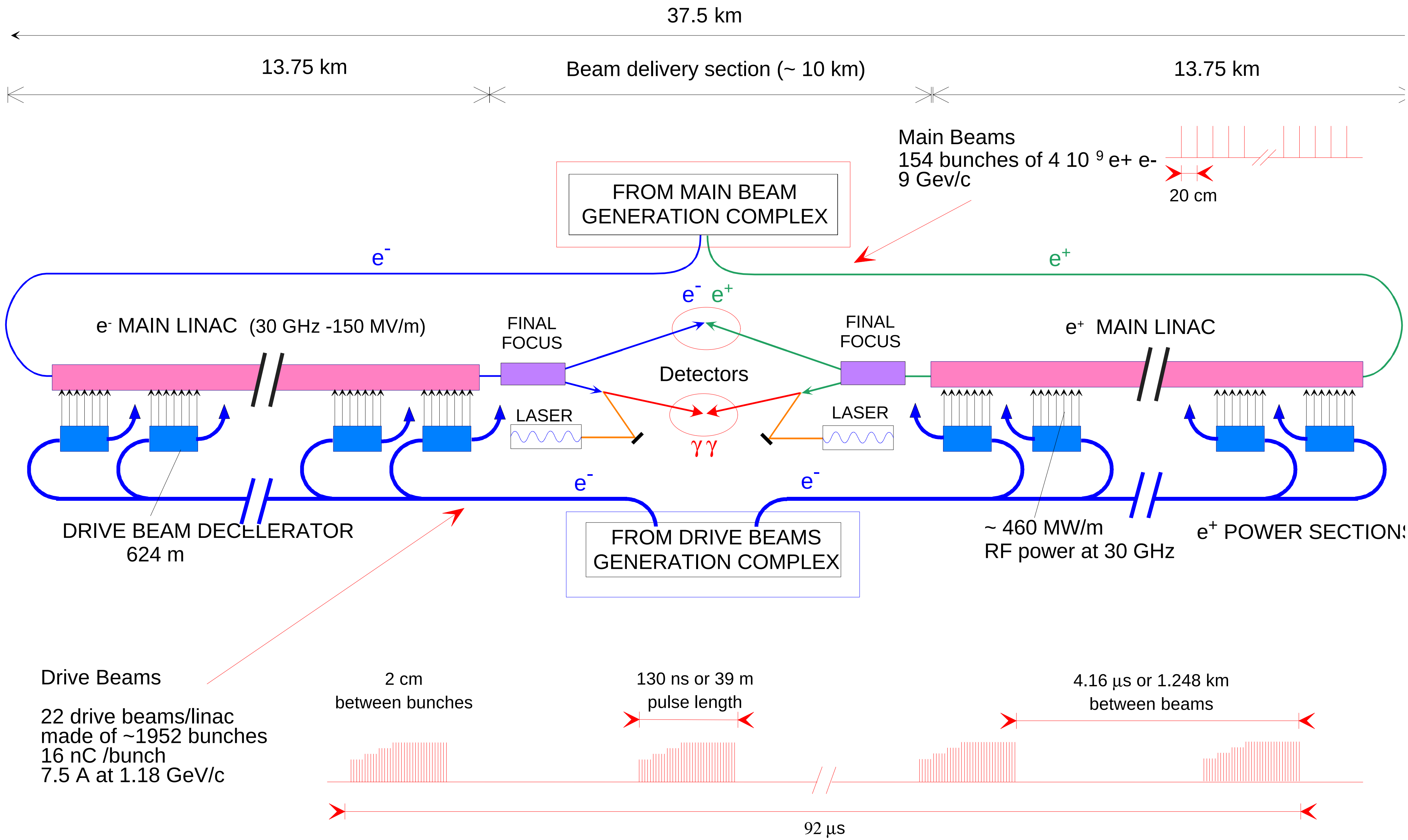
- **No active RF components (no klystrons or modulators)**
- **Single small-diameter tunnel (3.8 m - same as LEP)**

Overall Layout of the CLIC complex at 3 TeV c.m.



CLIC Parameters

Beam param. at I.P.	0.5 TeV	1 TeV	3 TeV	5 TeV
Luminosity ($10^{34}cm^{-1}s^{-1}$)	1.4	2.7	10.0	10.0
Mean energy loss (%)	4.4	11.2	31	37
Photons /electrons	0.7	1.1	2.3	3.2
Coherent pairs per X	700	$3\ 10^6$	$6.8\ 10^8$	$1.8\ 10^9$
Rep. Rate (Hz)	200	150	100	50
10^9 $e^{\pm}$ / bunch	4	4	4	4
Bunches / pulse	154	154	154	154
Bunch spacing (cm)	20	20	20	20
H/V ε_n (10^{-8} rad.m)	200/2	130/2	68/2	78/2
Beam size (H/V) (nm)	202/2.5	115/1.75	43/1	31/0.78
Bunch length (μm)	30	30	30	25
Accel.gradient (MV/m)	150	150	150	172
Two linac length (km)	5	10	27.5	40
Power / section (MW)	229	229	229	301
RF to beam effic. (%)	24.4	24.4	24.4	21.3
AC to beam effic. (%)	9.8	9.8	9.8	8.5
AC power (MW)	100	150	300	290

These parameters as you can see are very challenging and raise many questions.

On the machine side:

- **We have to study how to obtain stable collisions with 1 nm beams.**

Optical and inertial anchors combined with piezo-movers

- **Figure out how to extract the spent beams with large transv. ε and 100% energy spread.**

- **Design a crossing geometry that can handle closely spaced bunches (0.7 ns).**

To avoid multi-bunch kink instability require large crossing angle of 20 mrad (total), and in order not to lose luminosity require a crab crossing (phase jitter tolerances ? 0.1 degree ~ 2% lum. loss)

On the experimental physics side:

- **Have to take critical look at beam parameters to see if they have been optimised to give best physics conditions ? (e.g. trade-off between spectrum and luminosity)**

- **Initiate studies to see (i) what the detectors will look like**
  (ii) what sources and levels of background we will have.

beamstrahlung photons, coherent e+e- pairs (8.10^{8} for 3 TeV CLIC !), hadrons (especially neutrons – radiation damage – CCD device 3.10^{9} / cm^{2}), photons from SR in last dipole of final doublet, scattering from collimators (muons), incoherent e+e- pairs, ….

- **Prepare analysis tools to handle multiple collisions in detector (time / space resolution)**

- **Investigate ways to optimise the luminosity**

Beam/beam deflection scans, monitoring e+e- pair production, monitoring energy of spent beam

CLIC Physics Working Group

Started April 2000

main goals are to

1) identify and investigate key processes that can help to optimise the machine design

    luminosity spectrum, accelerator induced background, beam-beam background

2) explore the physics programme for CLIC and develop a preliminary detector design

3) compare the physics potential of CLIC to other collider options

    LHC, $\mu^+\mu^-$, ...

study started this year with 1)

2) and 3) will be addressed in the coming years

results will be presented

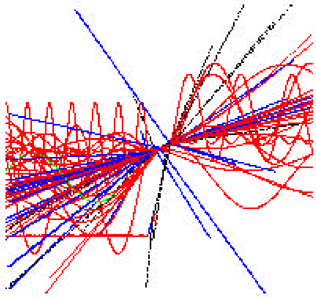
next workshop October 5/6 at CERN

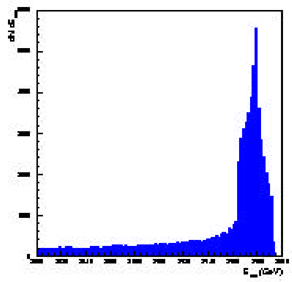
LCWS October 24-28 at FNAL

`http://clicphysics.web.cern.ch/CLICphysics/`

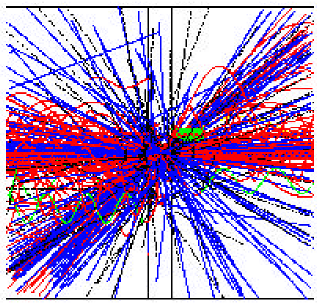
Analysis Tools

Physics Generator ((CompHep +) Pythia 6)
+ CLIC Beamstralhung Spectrum (Calypso)





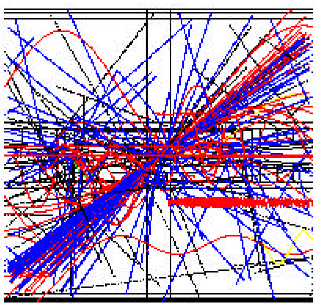
+ $\gamma\gamma \rightarrow$ **hadron Background** (Hades)



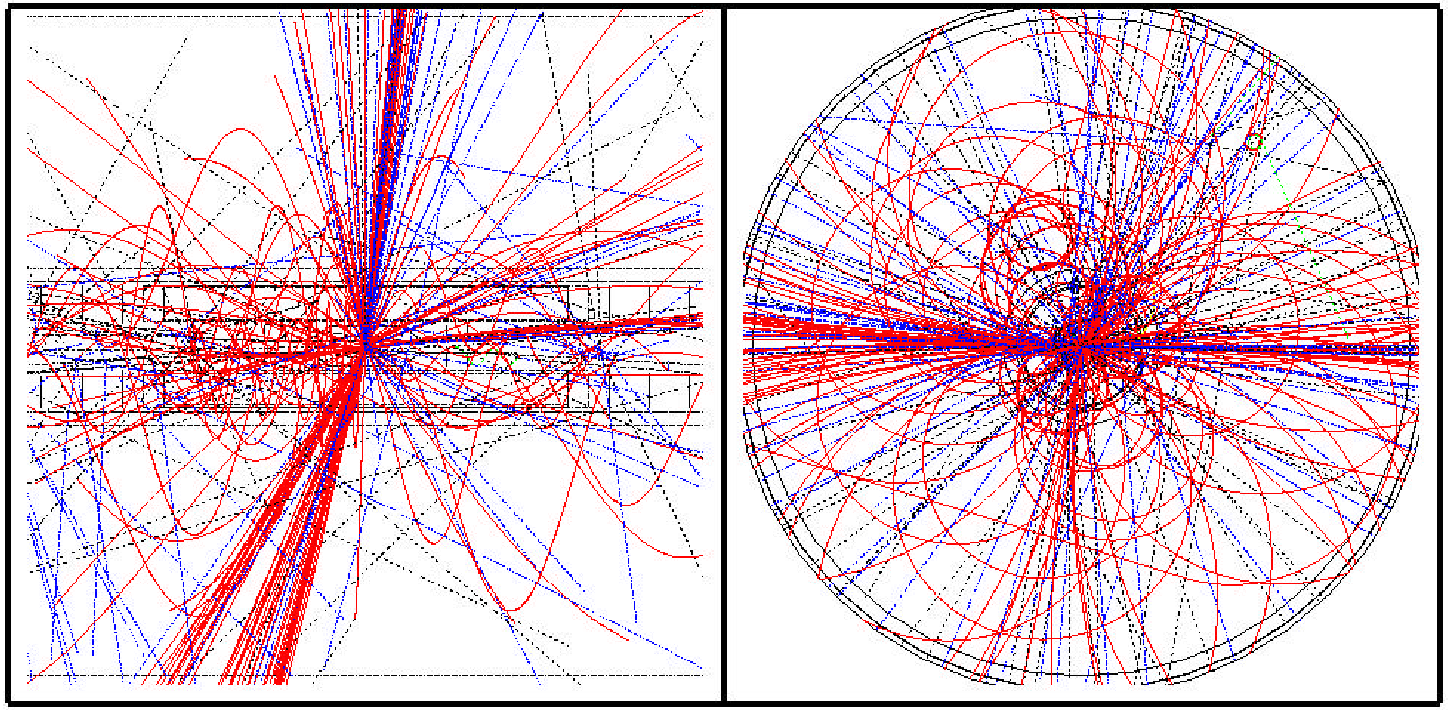
$\rightarrow$ Hepevt File

Geant **Full Sim**
(TESLA CDR Det.)
(Brahms **v.1**)

Simdet **Par. Smear**
(TESLA CDR Det.)
B = 4-6 T



$$e^+e^- \to H^+H^- \to t\bar{b}\,\bar{t}b$$
for $\sqrt{s} = 3$ TeV, $M(H^\pm) = 900$ GeV, $B = 4$ T



Luminosity spectrum

Question : What is the effect on luminosity spectrum of letting mean energy loss parameter go as high as 32% ?

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The table shows the percentage of luminosity contained in 1% and 5% of the c.m. energy

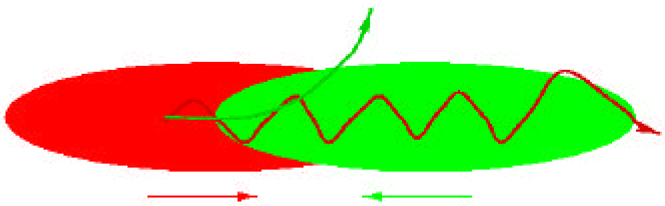
Energy (TeV)	0.5	1	3	5
L in 1% E_{cm}	71%	56%	30%	25%
L in 5% E_{cm}	87%	71%	42%	34%

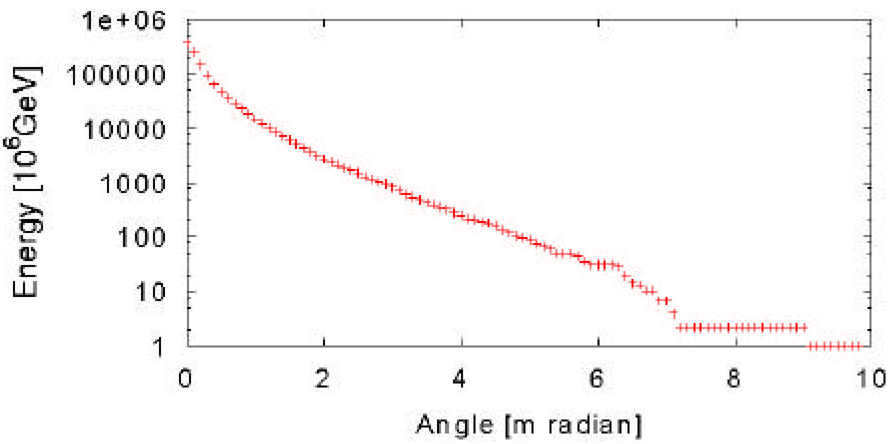
Spectrum does deteriorate with E - hopefully still acceptable

Coherent Pairs

E_{CM} [TeV]	no of pairs	$E_{coh}[10^9\,\mathrm{GeV}]$
0.5	700	10^{-4}
1	$3 \cdot 10^6$	0.8
3	$6.7 \cdot 10^8$	440
5	$1.8 \cdot 10^9$	1630

$\Rightarrow$ significant fraction of bunch charge ($4 \cdot 10^9$)





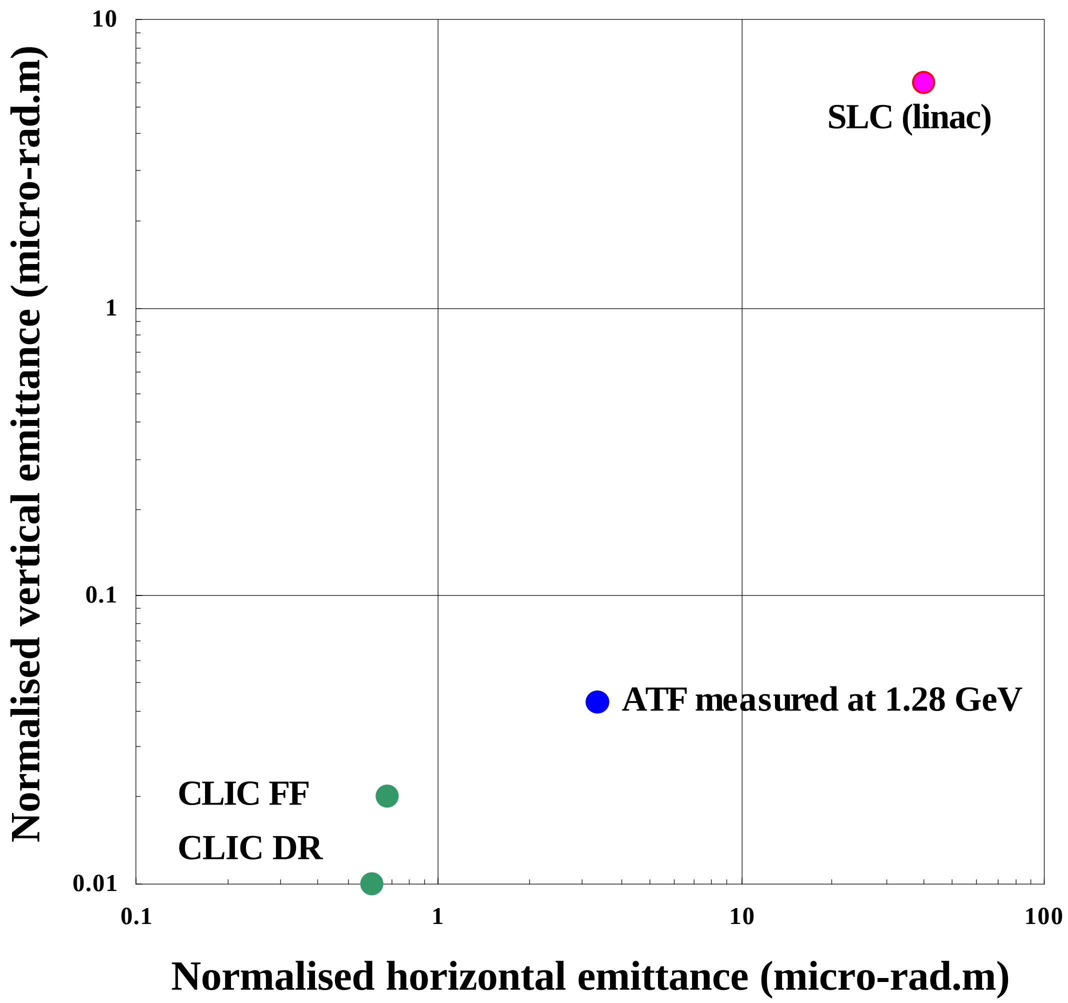
$\Rightarrow$ exit angle larger than $10\,\mathrm{mradian}$

Are our emittance goals realistic ?

This can be judged from this plot $\gamma\varepsilon_x$ versus $\gamma\varepsilon_y$

Reminder – have two requirements :

- **to produce small ε in DR**
- **to limit $\Delta\varepsilon$ during acceleration**



- **CLIC emittances typically 2-3 orders smaller than SLC.**
- **Missing factors ~ 4/ 8 (V/H) respectively for CLIC DR cf ATF DR**

New DAMPING RING DESIGN STUDIES are clearly required to demonstrate that the CLIC values are indeed feasible.

Present status: Have a base design for 1 TeV parameters but no serious design work has yet been done for the 3 TeV parameters.

Emittance blow-up in main linacs

How are we doing on limiting the blow-up in the main linacs ?

- Shown that - in spite of high W_T which scale with ω^3 - by choosing beam and machine parameters according to general scaling laws derived by CLIC team - $\Delta\,\varepsilon$ can be made independent of RF operating frequency.

$$\Delta\,\varepsilon \sim \omega^{0}$$

- In parameter list - budgeted for 100% blow-up.
- Our beam simulations however predict only 20% - so for moment have some margin - at least on paper.

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Simulations assume strong suppression of W_t in accelerating structures.

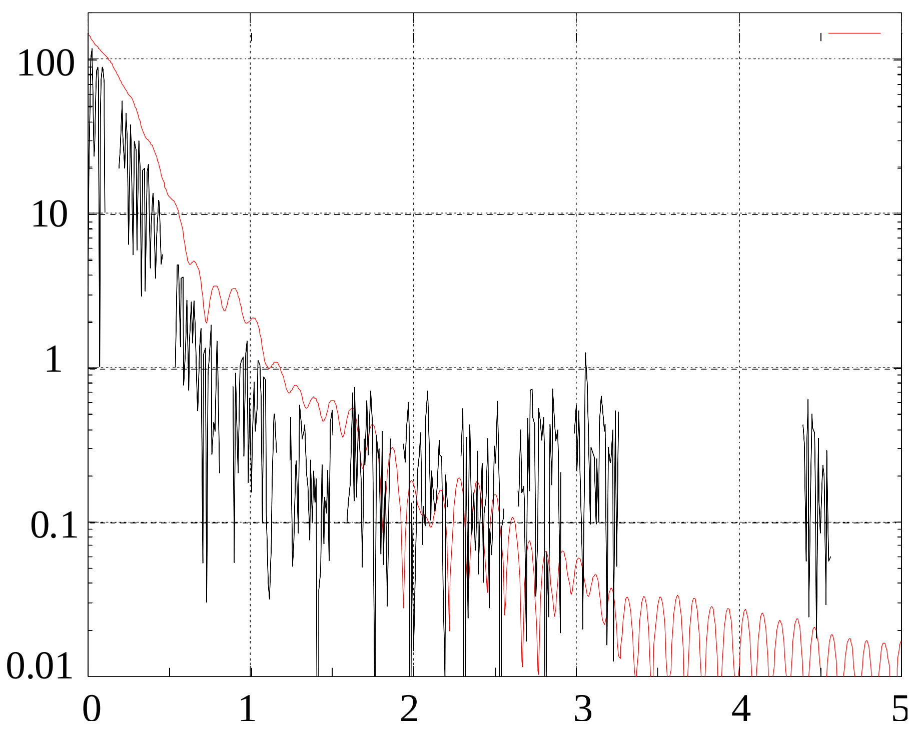
NEW CLIC ACCELERATING STRUCTURE

Major design concern : Suppression of disruptive W_T with time.

Each cell damped by 4 radial WGs terminated by discrete SiC RF loads.

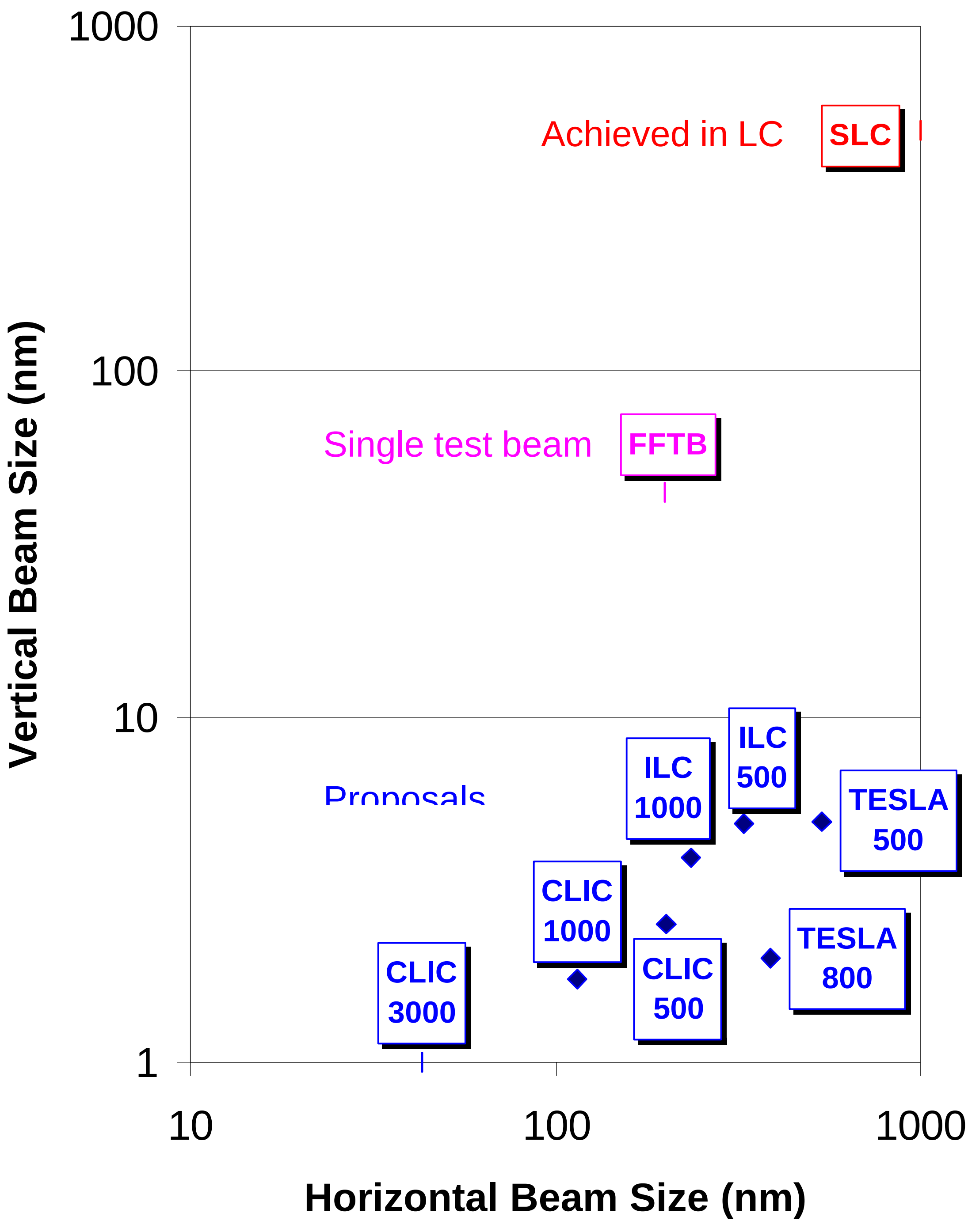
Calculations predict a very good suppression of W_T with time.
At 2nd bunch wake drops to 1% - after 8 bunches at 0.1 per mille level.

This predicted performance has been verified experimentally in ASSET.



R.M.S. Beam Sizes at Collision Point in Linear Colliders

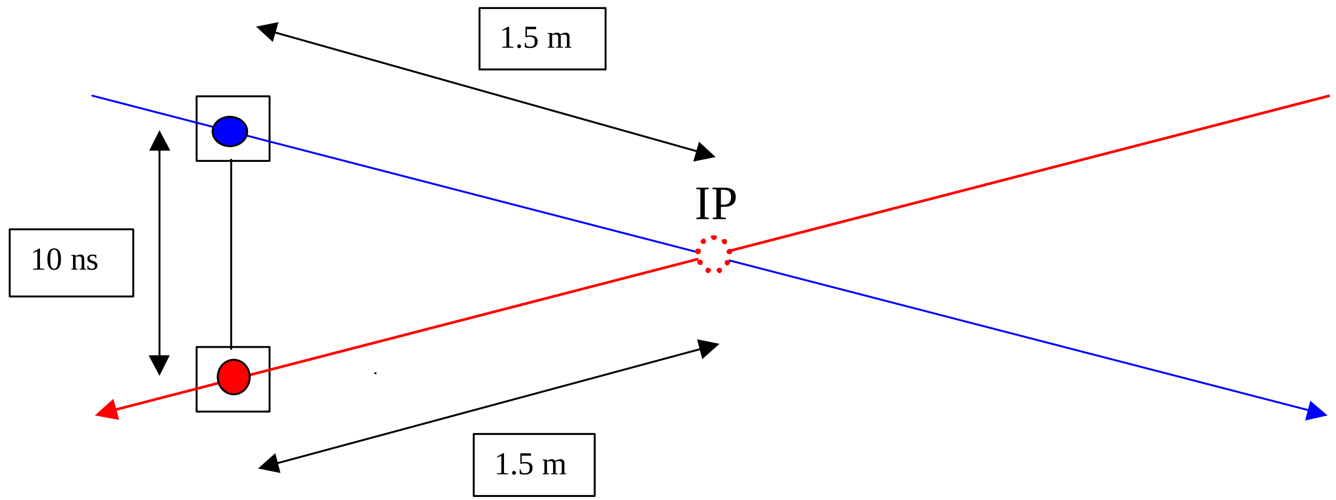
(1 nm : size of water molecule)



Use of INTRA-PULSE FEEDBACK being studied to keep beams in collision ?

Not so easy - CLIC has relatively short pulse length ~ 100 ns - scheme is as follows :

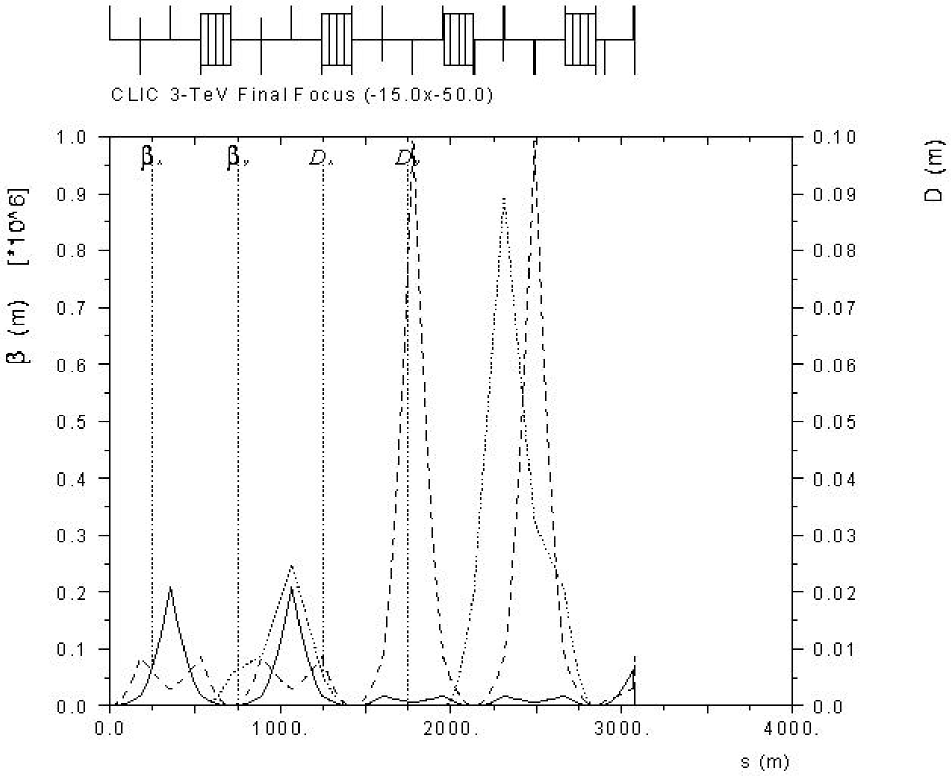
When beams collide with vertical off-set – receive strong kick from beam/beam interaction. Position of this deflected outgoing beam is measured at short distance from IP (RED bunch) and compensating signal is sent to a nearby kicker on the same side of the IP which corrects the incoming beam (BLUE bunch). Results in response time of ~ 20 ns.



Simulations for CLIC at 1 TeV using this scheme show that with a BPM resolution of 15 μm, the luminosity loss due to pulse-to-pulse vertical position jitter can be reduced by factor 3.

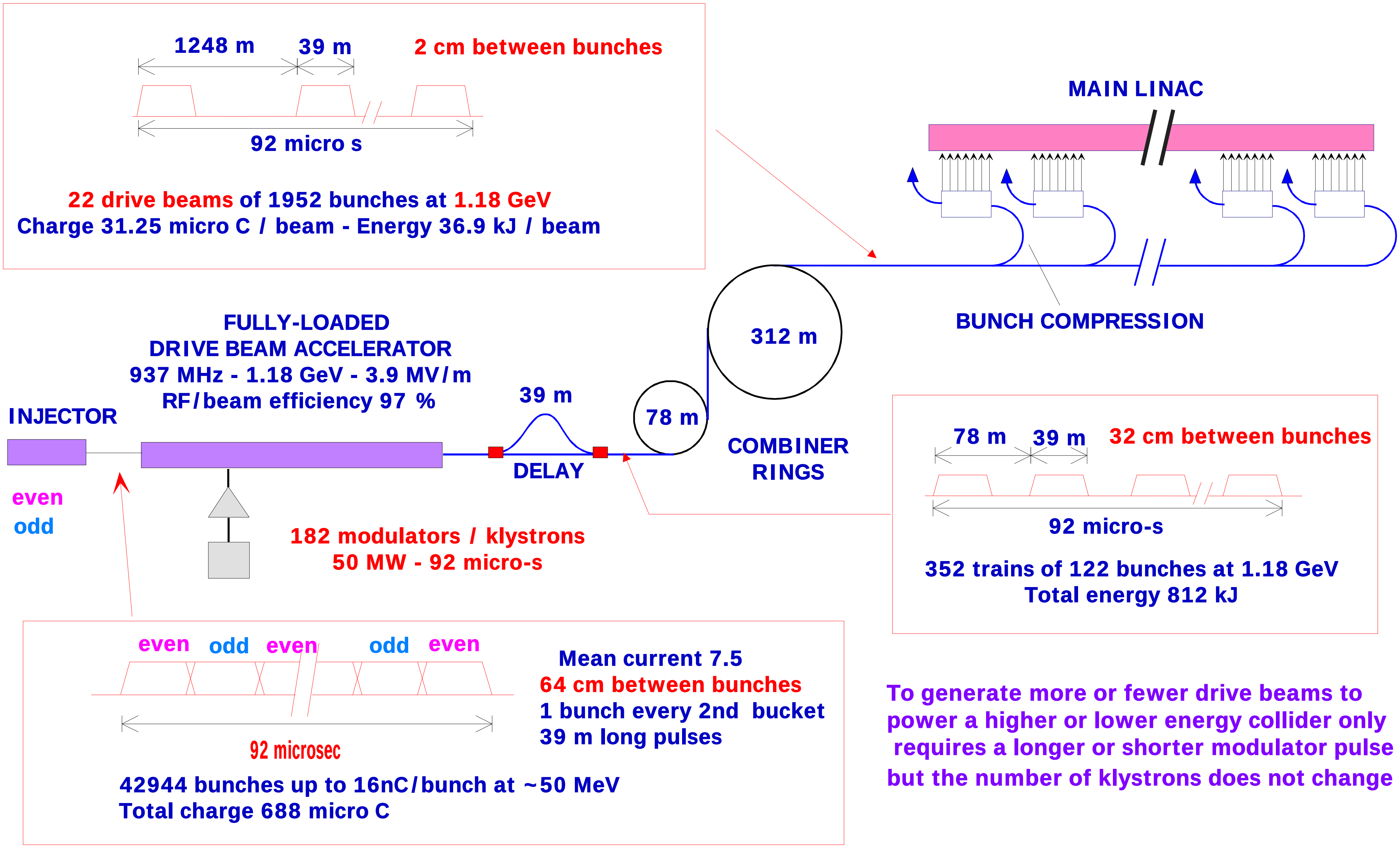
BEAM DELIVERY AND FF STUDIES (SL/AP)

FF design is at very preliminary stage



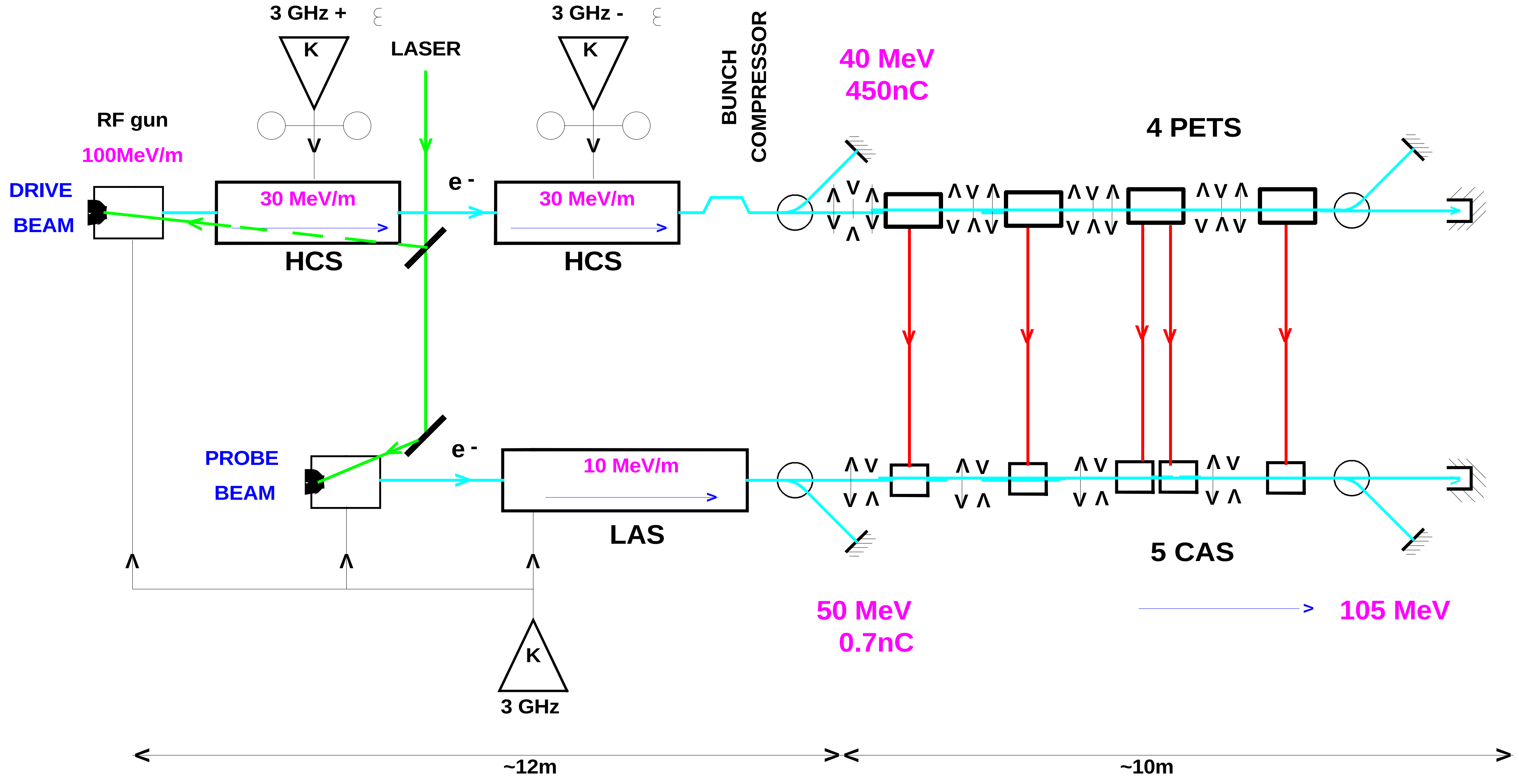
- **an optics found - looks quite promising - length per side ~ 3 km**
- **80% of ideal luminosity for 1% full-width flat energy spread.**
- **rms spot sizes in both planes are 20-30% larger than expected from the simple calculation using emittance and beta function at IP.**
- **To keep the overall length down – hope is to incorporate collimation system within the FF section where βs are large – needs to be studied.**
- **Jitter tolerances on final doublet for 2% Lum. Loss ~ 0.2 nm**

CLIC RF POWER SOURCE FOR 3 TeV COLLIDER



To generate more or fewer drive beams to power a higher or lower energy collider only requires a longer or shorter modulator pulse but the number of klystrons does not change

A DEMONSTRATION OF THE TWO BEAM ACCELERATION SCHEME IN THE CLIC TEST FACILITY



CLIC Test Facility CTF2

CTF2 built :

- **to demonstrate feasibility of the CLIC two-beam acceleration scheme**
- **to study generation of short, intense e- bunches using laser-illuminated PCs in RF guns**
- **to demonstrate operability of μ-precision active-alignment system in accelerator environment**
- **to provide a test bed to develop and test accelerator diagnostic equipment**
- **to provide high power 30 GHz RF power source for high gradient testing ~ 90 MW 15 ns pulses**

Present program is focused on high gradient testing of accelerating structures

RF BREAKDOWN OF ACCELERATING STRUCTURES

RF breakdown has been observed in both the NLC/JLC and CLIC prototype accelerating structures at gradients below the nominal values.

Special workshop organised at SLAC in September to discuss problem.

Conclusion (if there was one) : just don't understand the physics which initiates and sustains RF breakdown - more detailed studies clearly needed to investigate effects of : material, geometry, and cleaning and RF conditioning procedures.

The situation for CLIC is as follows.

In 1994 before we had 30 GHz power source we built a 26 cm 11.4 GHz low-group-velocity structure and tested it at SLAC to peak gradient of 154 MV/m (125 MV/m average) with 150 ns pulse length.

So here is a proof of existence of the very high gradients we are aiming for.

So what about the breakdown and damage observed in the CTF2 ?

Damage has been observed at relatively low gradients (60 MV/m) – so there is clearly a problem BUT we do not consider these results to be representative of what we can finally achieve. Why ?

(i) Damage confined to the input coupler which has a 40% over-voltage enhancement - can be taken out by modifying the design – this is foreseen.

(ii) Structures were exposed to air (and dust) for about 6-7 years and were operated under unusually poor vacuum (perhaps as bad as 10^{-3} torr).

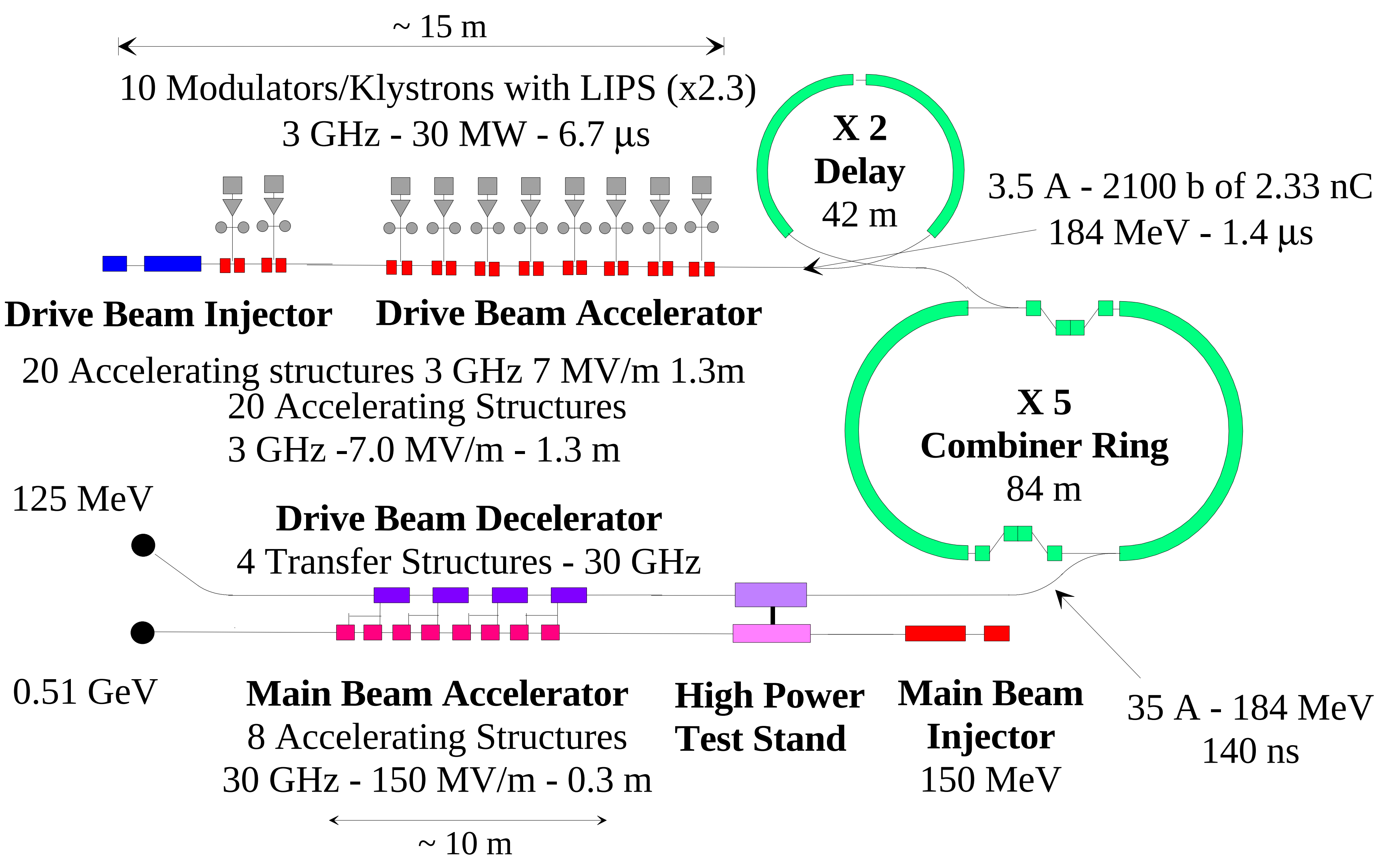
(iii) Structures were conditioned using aggressive conditioning procedures and with a limited number of pulses (CTF2 only runs at 5 Hz !).

Have to wait for new round of high gradient tests on structures with an improved coupler design and better vacuum conditions before we can really say if we have a serious problem or not.

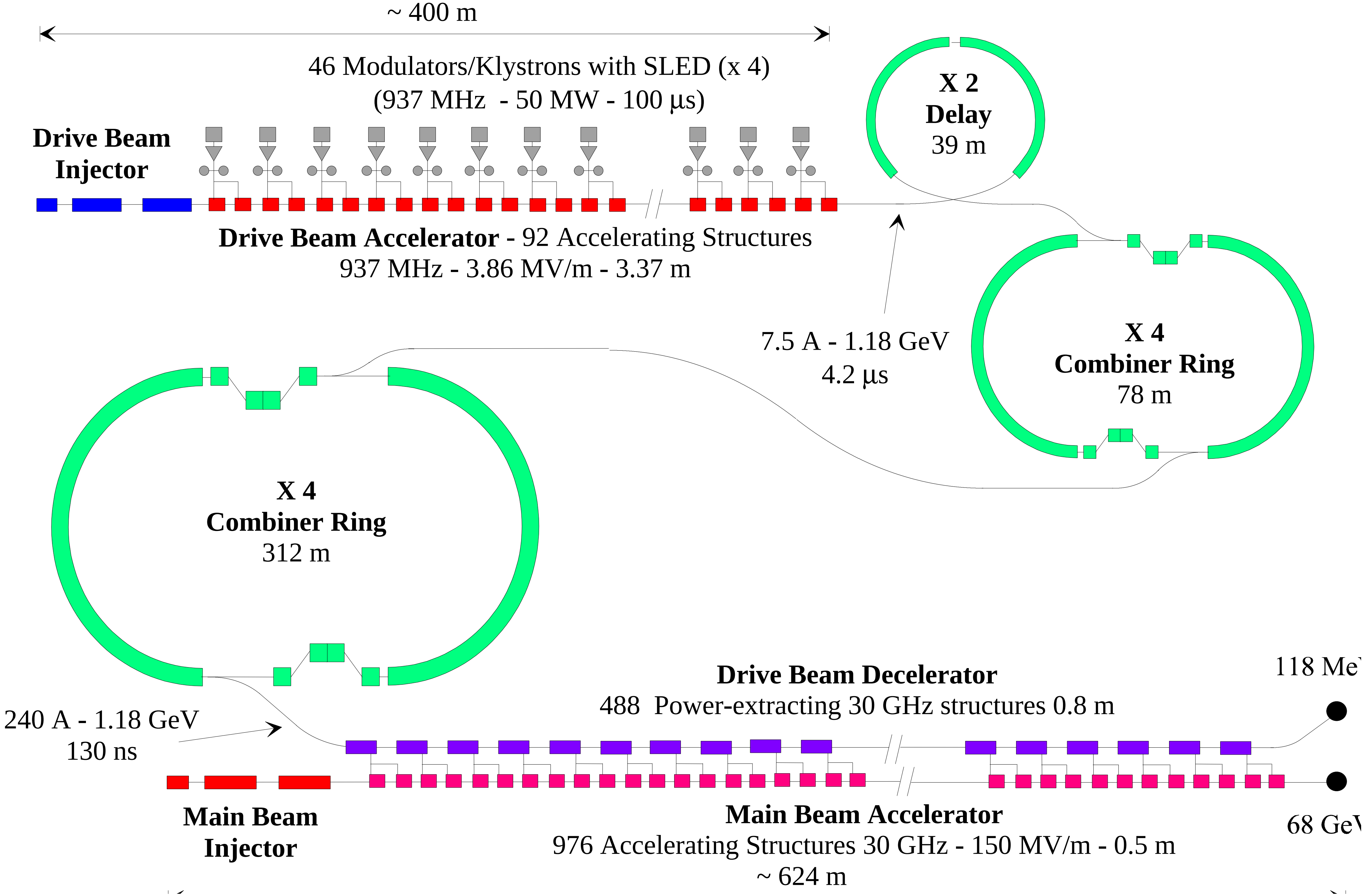
The new CLIC Test Facility CTF3

- **What comes after CTF2 ?**
- **Have plans for new test facility (CTF3) to demonstrate feasibility of new drive beam generation, acceleration and frequency multiplication scheme.**
- **To limit costs - generation and accel. done at 3 GHz rather than 937 MHz.**
- **Why 3 GHz ? Because when LEP stops at end of 2000 - can use 8 klystrons and modulators presently being used for LEP Injector Linac (LIL).**
- **We will generate a 3.5A 184 MeV 1.4μs long bunch train which after two stages of frequency multiplication (x10) will give us a 140 ns long beam with the nominal CLIC bunch spacing of 2 cm.**
- **This beam will be used to generate enough 30 GHz RF power to run the accelerating sections at the nominal CLIC values of 150 MV/m for 140 ns.**
- **This new facility will be housed in present LIL / EPA buildings.**
- **Before installing CTF3 existing LIL / EPA complex will be modified and used to do some proof-of-principle beam combination tests at low currents (0.3A).**

CLIC TEST FACILITY - CTF 3 - Nominal
Test of Drive Beam Generation, Acceleration & RF Multiplication by a factor 10



CLIC1 - Test of one drive beam of full energy



Research studies

CLIC

Question : What research studies are needed on the way to making CLIC a reality ?

- **To demonstrate accelerating gradients of 150 MV/m can be obtained for 130 ns.**
- **To develop the necessary 30 GHz technology - and in particular to build Accelerating structures, power-extracting structures, and BPMs.**
- **To demonstrate feasibility of new DB generation and power production scheme.**
- **To design a reasonable length FF and collimation section for 3 TeV.**
- **To demonstrate that the FF quadrupoles can be stabilised to sub-nanometer levels.**
- **Provide convincing proof that ultra-small emittances ($\varepsilon_{n\ H/V}$ ~ 500/10 nrad.m) can be obtained from DRs and that this emittance can be preserved in the main linacs.**
- **To demonstrate technical feasibility of producing very small spot sizes ($\sigma_{X/Y}$ = 43/ 1nm).**
- **To develop and demonstrate that intra -pulse feedback systems work.**
- **To convince ourselves we can do good physics with such strong beam-beam interaction.**
- **To build and successfully operate CLIC1.**